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36 p.
tables
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maps

Direct Reduction Processes

with Emphasis on Coal Based DRI Production

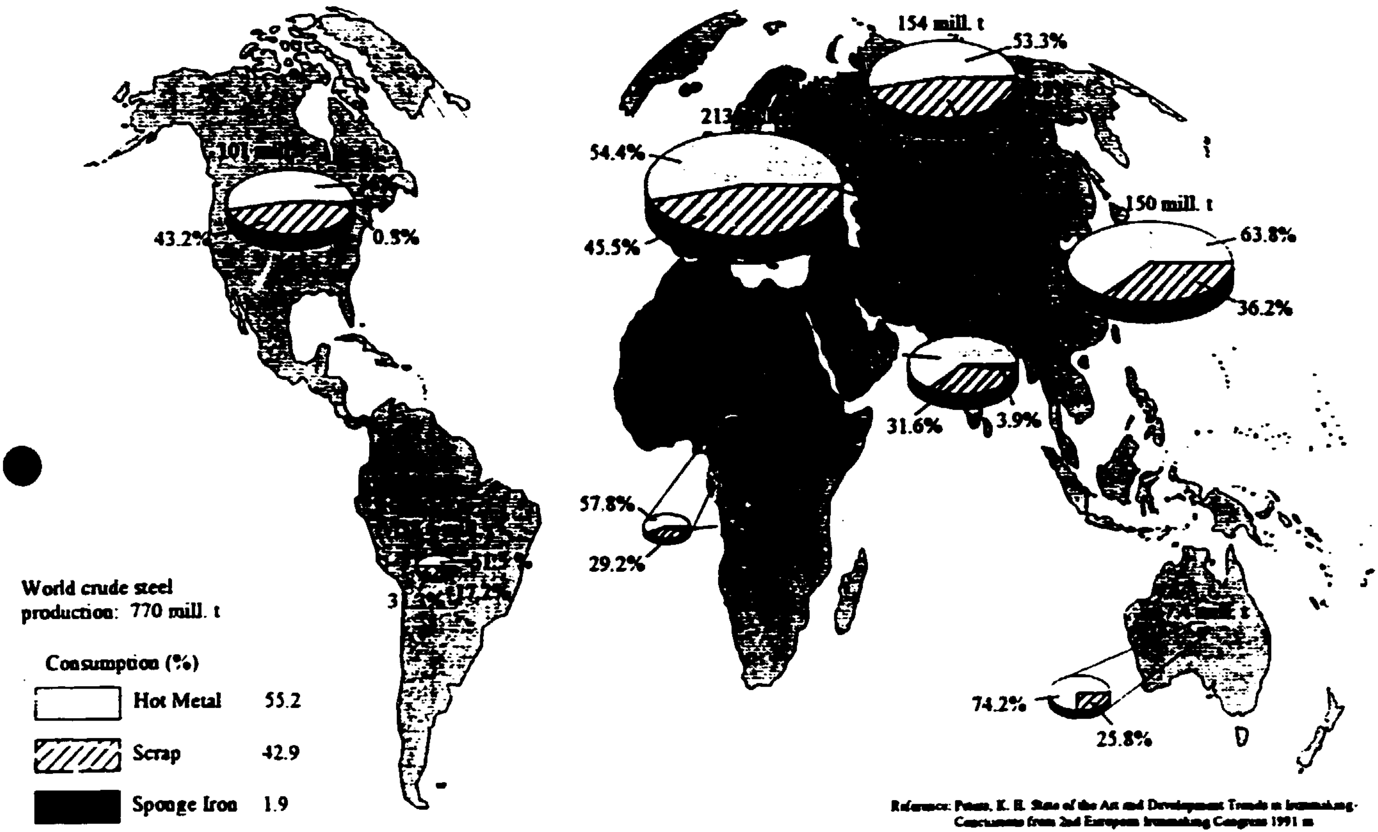
(Provision of scrap substitutes for mini-mills)

23rd February 1995

Contents

1.0 World steel production with distribution of pig iron/scrap/DRI

Percentage Consumption of Hot Metal, Scrap and Sponge Iron for World Crude Steel Production 1990

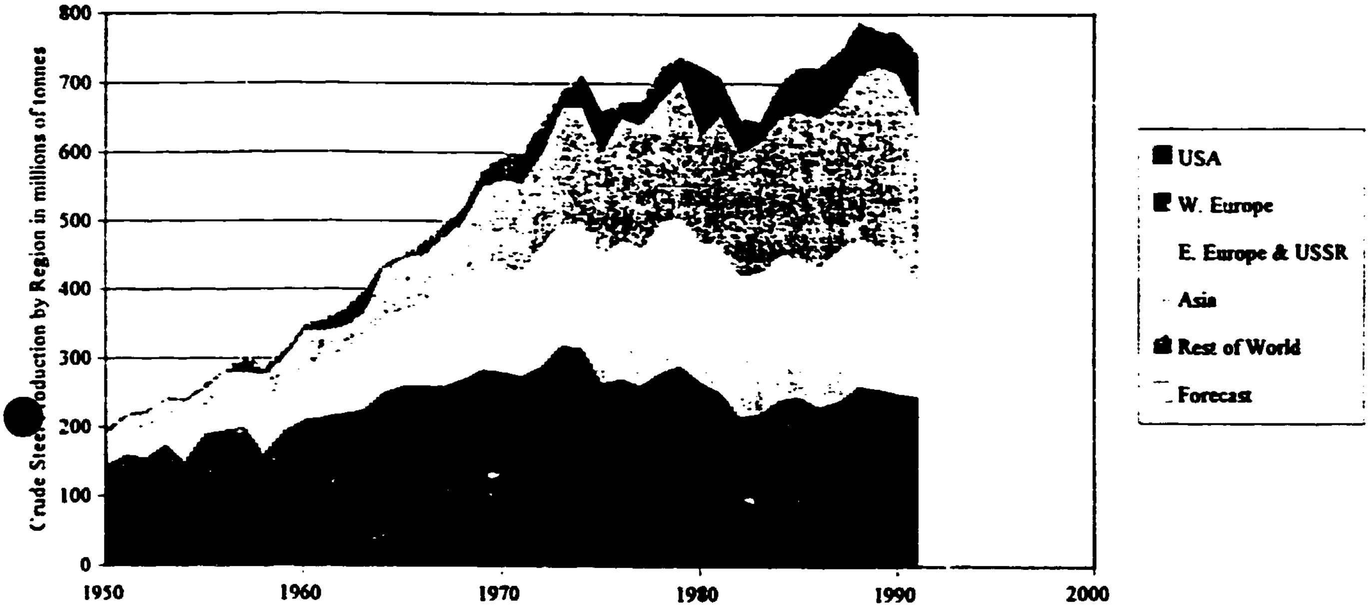


Reference: Peters, K. H. State of the Art and Development Trends in Ironmaking - Conclusions from 2nd European Ironmaking Congress 1991 in Glasgow. Coke Making Vol 4 1/1992

Since the end of the second world war, the production of raw steel has been continuously rising until 1974. In 1950, production reached 200 million tonnes, in 1960, over 300 million tonnes and in 1970 about 600 million tonnes. When the energy crisis began in 1974, 700 million tonnes was produced and then the steel production stabilised for the next ten years at this level.

In the 1980's there was again a slight increase to about 750 million tonnes. After a short recession phase, it is estimated until the year 2000, the steel production will increase to 800 million tonnes per year. The biggest rate of increase during the last 20 years was in Asia, with slight increases in production in Australia and Africa, whilst in Western Europe steel production has remained steady and in the USA and OECD countries, there was large production decrease. The american steel production decreased from about 100 million tonnes before 1980, to about two thirds of this value.

The growth of world steel production in recent decades can be attributed above all the growth of production in Asia



The basic materials for raw steel production are firstly pig iron, secondly scrap and thirdly DRI (Direct reduced iron).

1.1 Pig iron

The current production is between 500 and 550 million tonnes per year, with about 10% of the production going to foundries. The main part which is still 450 to 500 million tonnes a year is almost exclusively processed by oxygen blowing processes into steel. Export of pig or raw iron granulate is possible, but the quantites are quite low.

1.2 Scrap

There are the following types of scrap:

- Home scrap, which is very clean and of reliable quality
- Obsolete scrap, which has many contaminants

The quality of obsolete scrap is inherently poor. Unlike home or prompt industrial scrap, which is generally clean and free of tramp elements, and at worst coated in zinc, obsolete scrap is the leavings of society and brings with it a host of contaminants.

Cu Of these the worst is copper. Associated with bearings, electrical wiring and motors, it moves easily with the scrap. Being noble, it quickly finds its way into liquid steel and cannot be removed. While in bar products it can be a strength raiser, it also leads to hot shortness and cannot be tolerated in ductile flat products.

Sn Tin is another contaminant, being found in bearings and bronzes and on recovered steel cans.

Zn Zinc does not cause product problems, but generates fume and if dumped without treatment can lead to groundwater contamination. Zinc is often associated with

Pb Lead which presents a known health hazard in addition to its environmental effects

Ni - Cr - Cd - Mo A series of common tramps which serve a valuable place as alloying elements in stainless and special steels, but merely serve to degrade properties in high grade low residual flat product steels.

By attention to detail the merchant can reduce the quantity of copper getting into valuable scrap, but there are economic limits to what he will or can afford to undertake. An indicative pattern of contamination and what yard work can achieve is indicated below

Scrap Type	**Present**	**Yard Treatment**	**Detinning**
Shred	0.23% Cu	0.20% Cu	
Heavy Melt 1	0.25% Cu	0.20% Cu	
Heavy Melt 2	0.50% Cu	0.35% Cu	
Tin Cans	0.40% Sn		0.02% Sn

Steel Product	**Cu Limit**	**Sn Limit**
Forging - Bar Products	0.35%	0.04%
Deep Drawing	0.06%	
Ductile Flat Products	0.05%	0.04%

But available quantities of scrap show two opposite tendencies :

The home scrap is reduced steadily by the introduction of the continuous casting process, whilst the obsolete scrap quantities increase. It follows that reasonable quantities of high grade scrap are only available in certain areas.

1.3 Sponge iron (DRI)

The most part of DRI in steel production is found mainly in South America and Africa., whilst in South Asia, the production is somewhat lower and the american and euriopean steel producers only use very low quantities of DRI.

Hardly and sponge iron is utilised in Eastern Asia and Australia. Due to the trend towards mini-mills, the requirement for scrap of high quality is steadily increasing.

At present mini-mills are concentrating on scrap selection as the principal (and least expensive) means by which tramps and deleterious materials can be lowered to a concentration that will enable them to produce the better grades of steel for which they are aiming. However as we have noted before, there are limits to the extent to which this strategy is effective, and the difficulty increases continually as more obsolete feed enters the return scrap stream. Dilution, the last option, takes three common forms

- use home scrap as discussed earlier nor generally an available option to mini-mills
- use premium grade scrap quantity limited, premium priced and still not without the some tramps present
- use scrap substitutes

Scrap substitutes derive directly from iron ore and thus bring the benefits of cleanliness that come naturally through the integrated process. The most commonly considered scrap substitutes are

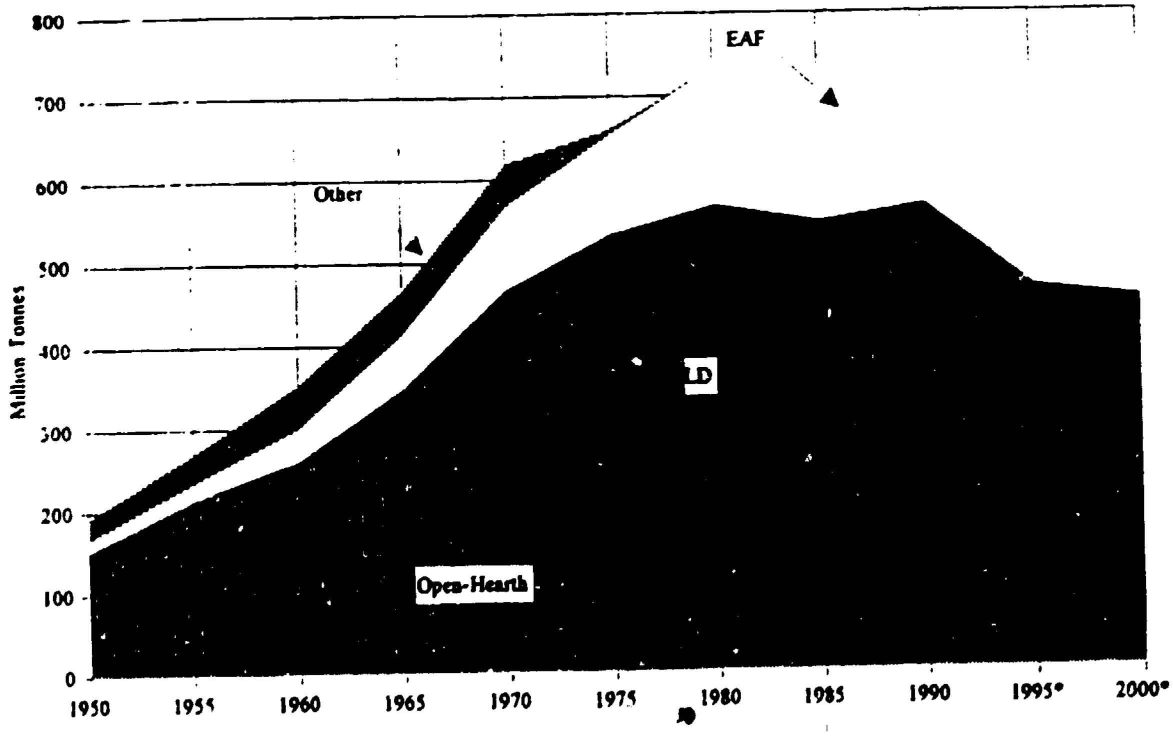
- direct reduced iron iron ore is reduced to a high degree of metallisation by contact with gas or coal
- basic iron iron ore is smelted in a blast furnace to a castable metal. Basic iron varies from the other major grade, foundry iron, which has much higher levels of silicon and other additives and represents feed tailored to steelmaking needs. It can he cast in many forms, such as pig iron, flat iron of granulated iron.
- iron carbide iron ore is reduced in contact with gases rich in carbon to produce small crystals of Fe_3C. Unlike the two previous processes this has not yet achieved commercial reliability at an industrial scale.

The disadvantage of the use of pig iron is that this product hardly exists any more on the market. A further alternative may be Iron Carbide but to date, this is not yet available on the market. Therefore, it follows that scrap has to be replaced by DRI.

In COMESA countries steel is - with the exception of ZISCO - produced mainly out of scrap via the EAF-route. Local scrap is quite limited and with increasing production the countries will face a greater demand in DRI as a scrap substitute.

As known so far, natural gas is not easily available however some coal deposits are known in the region. Therefore DRI processes based on coal will have predominant importance for the production of scrap substitutes. Such process routes will be treated later under item 5.

2.0 Overview of the various methods of producing steel



This picture shows that the szenario of steel production processes during the last 50 years has changed considerably. The market-leaders are the oxygen blowing and the electric arc furnace processes nowadays. The Siemens-Martin process, which in earlier times, dominated steel production, is being slowly phased out, whilst the old converter processes have long since finished in the 1960`s and 1970`s.

In the following sections, those important processes will be described, with the statistics showing that the LD process has passed it`s highest production point but the use of electro-ovens is still increasing. Due to the universality of the new EAF processes, which allow the use of liquid pig iron up to 50% beneath scrap and sponge iron, the range of utilisation of the electro-oven is also spread into the palette of high quality steel. Therefore the EAF with it` s low investment costs is predestined to take over in integrated mini-mills.

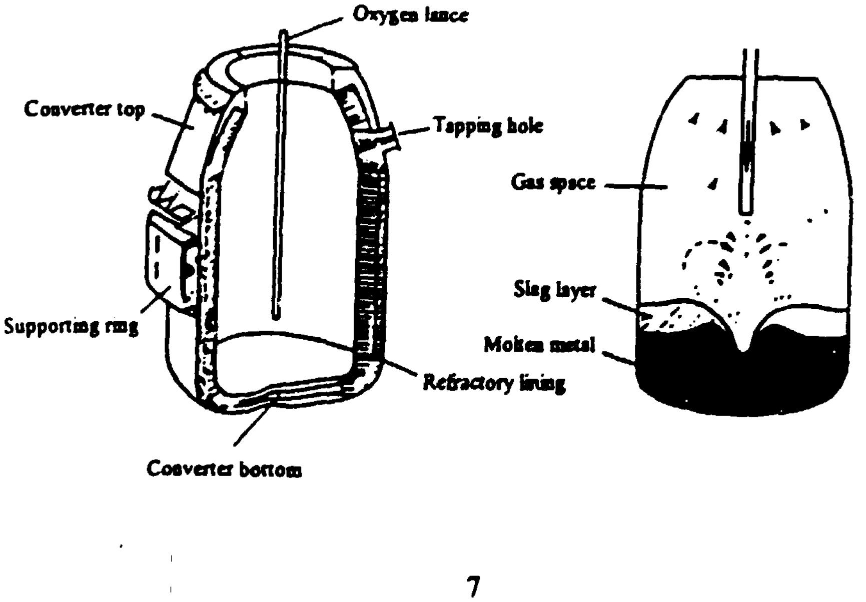
2.1 The Siemens-Martin Open Hearth Process

In 1960, the Siemens-Martin open hearth process produced ca. 70% of the world`s crude steel, but this rapidly declined following the growth of the oxygen-blowing and electric steel processes, and ceased operation after a few years.

It was developed for melting scrap, and was characterised by its great flexibility with respect to the proportions of pig iron and scrap used. The tank shaped furnaces are heated by fossil fuels such as gas or oil, burned in air. The regenerative air preheating invented by Siemens takes place in „checker chambers" that contain refractory bricks heated by the waste gas, and are situated under the furnace. The combustion temperatures achieved enable steel scrap to be melted.

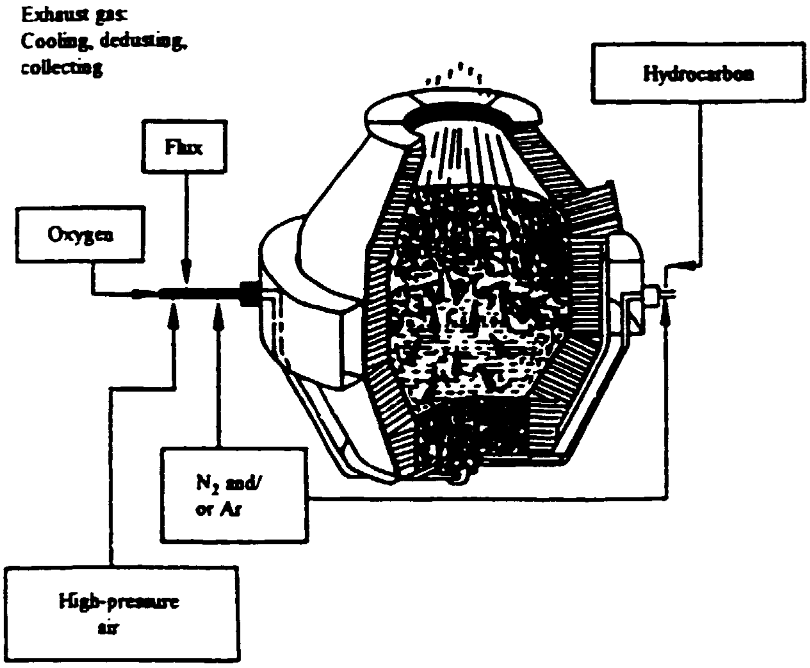
The capacity of these furnaces is 50 - 1000 t. The use of air for combustion leads to the production of large quantities of waste gas, whose purification, sometimes including desulphurization, is difficult and expensive. Additional oxygen, introduced through lances or burners (tandem furnaces), has been used to improve operation, but this leads to severe erosion of the refractory lining. The open hearth process has in general lost its importance, as it cannot achieve either the output or flexibility of blowing processes.

2.2 LD and OBM Processes

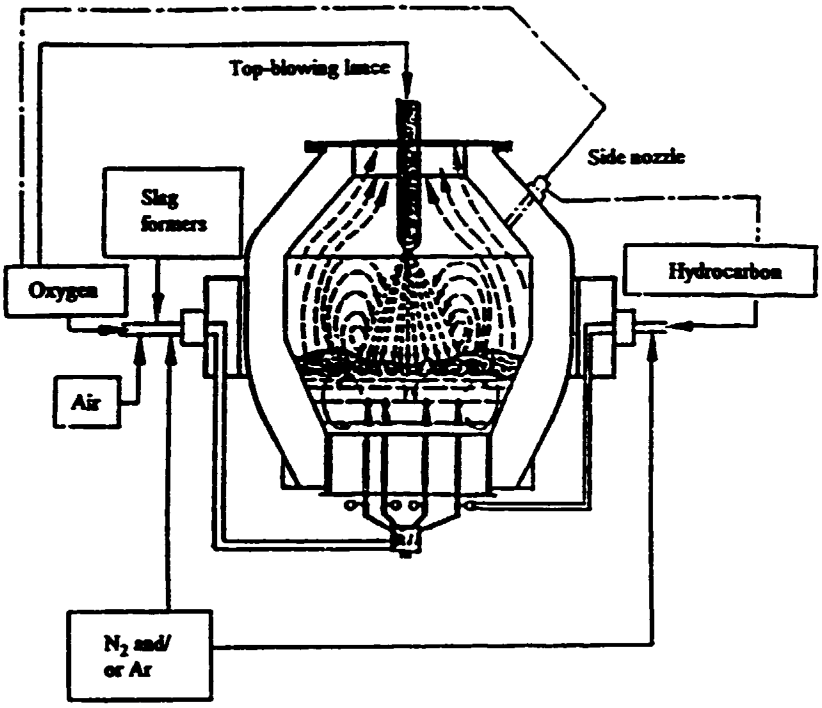


The first LD (Linz-Donawitz) converter (above), with a capacity of 30 t, was operated in Linz in 1952. The decarburization reaction is greatly speeded up by the use of pure oxygen, giving blowing times of 10-20 min. The oxidation enthalpies result in lower heat losses and enable more scrap or ore to be added. The converters have total charge 50-400 t, and are lined with dolomite or magnesite bricks.

Oxygen is injected from above through a water-cooled lance with several nozzles, onto the surface of the melt. The high-pressure jets of oxygen oxidise the iron, carbon, and other elements at rates depending on their affinity for oxygen. The gas reactions cause thorough mixing of the molten materials, and this is maintained after completion of the blowing process by purging bricks built into the base of the vessel. Temperatures of 2500-3000°C are produced in the central reaction zone, and a reactive slag is rapidly formed from the added lime and the oxidised iron.



The OBM (oxygen blowing technique), as shown above is a modification of the air blast processes was developed in 1968- 1969 in Sulzbach-Rosenberg. Pure oxygen is passed through bottom tuyeres into the melt. These tuyeres are highly stressed, and are stabilised by cooling them with hydrocarbons. The cooling effect is a result of the endothermic decomposition of the hydrocarbons in the hot melt. The OBM process causes more intensive mixing of the steel and the slag compared with the method of blowing in the oxygen from above. This gives improved reaction kinetics and yield, owing to the lower iron content of the slag. The advantages of the more rapid formation and the less violent blow can be enhanced by adding powdered lime through the bottom of the converter. along with the oxygen. However, the capacity of the OBM process for melting scrap is limited in comparison with the LD process, owing to the lesser extent of afterburning of the waste gases, and the smaller amount ofiron oxidation.



Combined converter

The combined technique in use today provides:

1. Homogeneous melts due to rapid breakdown of the scrap.
2. Reduction of the blowing cycle time by 25%.
3. Higher yield of iron and alloying elements.
4. Better control of the chemical composition.
5. Improved purity.
6. Lower quantity of slag and reduced tendency for it to be ejected.
7. Increased lifetime of the converter lining.
8. More favourable conditions for the measuring systems for process control.

At the end of the oxygen treatment, the converter is tilted and the steel tapped into a ladle (a steel container with bottom-pouring facility and refractory lining). The steel is separated from the slag during emptying of the converter by means of a floating stopper introduced into the tapping spout. This prevents the slag, which is of a lower density, from running out. Alternatively, an electromagnetic measurement in the tapping system can give a signal for the emptying process to be stopped.

2.3 Electric Steel Process

In the electric steel process, the heat required is obtained not by oxygen combustion of the accompanying elements in the pig iron, but from electrical energy. The conversion of electrical energy into heat can be achieved by an electric arc, induction, or plasma furnace. Electric steel processes are based on the use of scrap, with small amounts of solid pig iron. For a long time, the use of these processes was limited to the production of special steels, as energy consumption was high and the economics were unfavourable. Increases in the size of power stations and the capacity of electrical distribution systems have enabled batch weights to be increased, and the costs of energy, electrodes, refractory material, and capital investment to be reduced. Today, this process is second in importance only to the oxygen-blowing process in world crude steel production.

Over 90% of all electric steel produced is by the use of a.c. electric arc furnaces (see Fig. below). Three graphite electrodes carry the current through the furnace roof into the charge of metal. The electric arc formed melts the charge at temperatures up to 3500°C. The furnace has the following essential components: the vessel or shell with a furnace door and a tapping hole; the roof which can be removed for charging; electrode arms which support the electrodes; tilting equipment for emptying the furnace; the furnace transformer; and the measuring and control equipment.

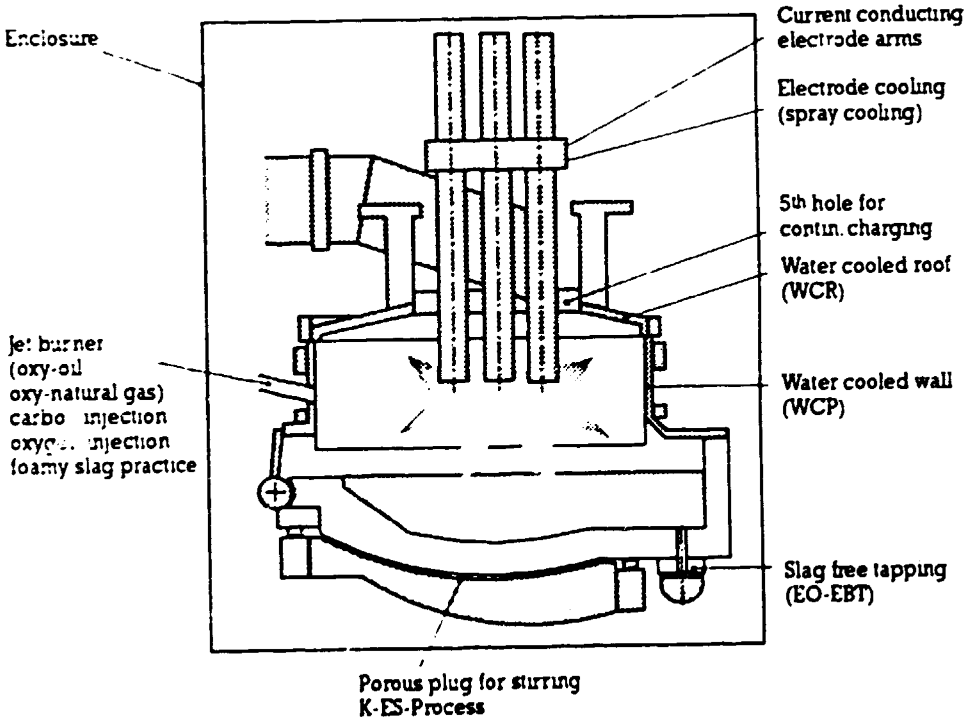
The melting procedure for the electric arc furnace compromises the following stages:

1.) Charging
2.) Melting
3.) Oxidation (decarburation), with an increase in temperature
4.) Tapping

The raw materials (scrap, sponge iron, pig iron, alloying elements, etc.) together with the required additives (lime, coal, ore, etc.) are loaded into special charging buckets which are then emptied into the furnace through a bottom opening. To fill the furnace, two or three charging operations are required, between which the scrap is partially melted.

The melting process begins with switching on the current and striking the arc. A supplementary blow with oxygen and fuel-oxygen mixtures accelerates melting and reduces current consumption. The duration of the melting period is determined by the electric power limit and the maximum heat load of the furnace shell.

Process automation



Oxidation of the elements, such as silicon, manganese, carbon, phosphorus, and sulfur begins during the melting phase as the liquid reactants, steel and slag, react with the added oxygen. The gaseous carbon monoxide formed from the reaction between the iron oxide and the carbon causes bubbling in the melt and purges the hydrogen and nitrogen. Removal of the phosphorus as calcium phosphate in the slag during the oxidation phase is important, and all the other metallurgical processes take place during the reductive secondary metallurgical treatment in the ladle or ladle furnace.

After the steel has reached the required temperature, the tap hole is opened and the furnace is tilted to empty it into the ladle below.

The essential characteristics of modern electric steel production are:
1.) Process automation
2.) Enclosure of the furnace
3.) Preheating of the scrap
4.) Water-cooled wall and roof elements
5.) Gas/oil-oxygen jet burners
6.) Foam slagging
7.) Current-carrying supporting arms for the electrodes
8.) Electrode cooling
9.) Facilities for charging through the furnace roof
10.) Bottom stirring devices
11.) Slag-free tapping (eccentric bottom tap hole)

Another new development with growing importance is the Direct Current Electric Arc Furnace (DC-EAF) which has some advantages with regard to the normal Alternating. Current - Electric Arc Furnace (AC-EAF) for instance:
- lower electrode consumption
- less influence to the electrical grid (less flicker)

3.0 Overview of the DRI plants world wide

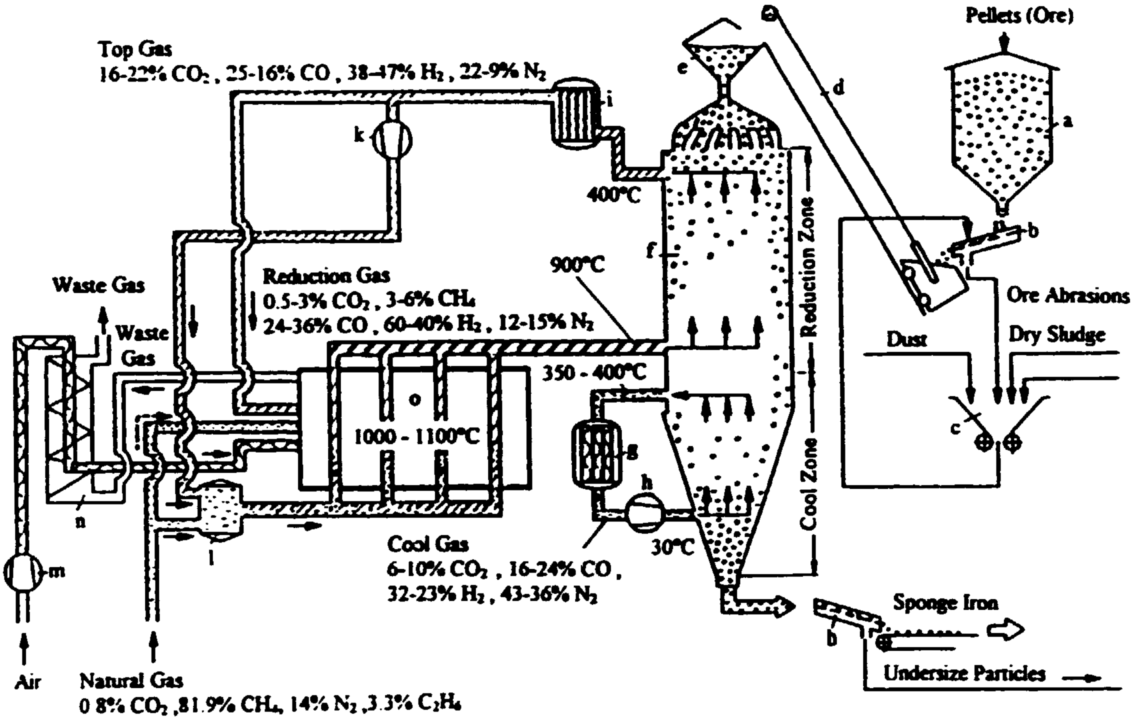
Customer	**Location**	**Capacity tpy**	**Process**
	Middle East/North Africa		
QASCO	Umm Said.Qatar	400.000	Midrex
ASCO	Ahwaz.Iran	1.200.00	Midrex
Madeed I	Al-Jubail.Saudi Arabia	800.000	Midrex
Madeed II	Al-Jubail.Saudi Arabia	650,000	Midrex
ANSDIC	El Dikheila.Egypt	716,000	Midrex
LISCO I	Misurata.Libya	1.100,000	Midrex
NISCO	Mabarakesh.Iran	3,200.000	Midrex
SEIS I	Iraq	543,000	HYL-I
SEIS II	Iraq	925,000	HYL-I
NISCO	Iran	1,030,000	HYL-I
	Asia/Oceania		
SGI	Labuan Island.Malaysia	650,000	Midrex
Essar Steel I & II	Hazira	880,000	Midrex
Essar Steel III	Hazira	440,000	Midrex
NDIL	Roigod.India	1,000,000	Midrex
PTKS I	Indonesia	560.000	HYL-I
PTKS II	Indonesia	560,000	HYL-I
PTKS III	Indonesia	560.000	HYL-I
PTKS IV	Indonesia	560,000	HYL-I
Grasim	India	750,000	HYL-III
PKTS	Indonesia	1.350,000	HYL-III
PSSB I	Malasyia	600,000	HYL-III
PSSB II	Malasyia	600.000	HYL-III
Unido/SIIL		35.000	SL/RN
Orissa Sponge Iron	India	150.000	ACCAR
Tata Iron & Steel	Jamshedpur.India	90,000	TDR
	Japan		
Nippon Kokan		400.000	SL/RN
	Australia/New Zealand		
Western Titanium	Australia	15.000	SL/RN
New Zealand Steel I	New Zealand	175,000	SL/RN
New Zealand Steel II	New Zealand	900,000	SL/RN
	Latin America		
SIDERCA	Campana.Argentina	330.000	Midrex
SIDOR I	Matanzas.Venezuela	350.000	Midrex
SIDOR II	Matanzas,Venezuela	1,275.000	Midrex
Aändor	Villa Constitucian.Argentina	600.000	Midrex
ISCOTT I & II (III)	Point Lisas,Trinidad & Tobago	840,000	Midrex
MINORCA (OPCO)	Puerto Ordaz,Venezuela	830.000	Midrex
VENPRECAR	Matanzas.Venezuela	600,000	Midrex

Customer	Location	Capacity tpy	Process
Hylsa 1M	Mexico	105.000	HYL-I
Hylsa 2M	Mexico	630,000	HYL-I
Tamsa	Mexico	280,000	HYL-I
Usiba	Brazil	225,000	HYL-I
SIDOR I	Matanzas, Venezuela	360,000	HYL-I
SIDOR II	Matanzas, Venezuela	2,110,000	HYL-I
Hylsa 2M5	Mexico	250,000	HYL-III
Hylsa 3M5	Mexico	500,000	HYL-III
Sicartsa I	Mexico	1,000,000	HYL-III
Sicartsa II	Mexico	1,000,000	HYL-III
MINORCA (OPCO)	Puerto Ordaz, Venezuela	400,000	FIOR
Acos Finos Piatini		60,000	SL/RN
Stelco		360,000	SL/RN
Siderperu		120,000	SL/RN
	North America		
Georgetown Steel	Georgetown, SC, USA	400,000	Midrex
Sidbec-Dasco I	Contrecoeur, Que, Canada	400,000	Midrex
Sidbec-Dasco II	Contrecoeur, Que, Canada	600,000	Midrex
Niagara Metals	Canada	30,000	ACCAR
Rockwood		60,000	DRC
	Western Europe		
HSW	Hamburg, Germany	400,000	Midrex
British Steel	Hunterston, Scotland	800,000	Midrex
	CIS/Eastern Europe		
OEMK	Stary Oskal, Russia	1,667,000	Midrex
	Africa		
Delta Steel	Aladja-Ovwain, Nigeria	1,020,000	Midrex
Highveld		2,000,000	SL/RN
Highveld II		600,000	SL/RN
ISCOR	Vanderbijlpark	720,000	SL/RN
Dunswart Steel		150,000	Krupp
Scaw Metals	Germiston	75,000	DRC
Total		41,980,000	
Natural Gas based processes		36,040,000	
Coal based processes		5,940,000	

4. Gas based DRI Processes

4.1 Process alternatives

4.1.1 MIDREX (Midrex Corporation, Kobe)



Key

a	Storage bunker for pellets or lump ore	h	Fan for circualting gas
b	Vibrating screen sieve	i	Scrubber (removal of dust and water vapour)
c	Briquetting press	k	Fan
d	Conveyor	l	Gas mixer
e	Sluice	m	Fan
f	Reduction shaft	n	Recuperator
g	Water cooler	o	Gas converter

In this process reduction takes place in a counterflow shaft furnace with a gas reformed in a special gas reformer. The iron ore is charged at the top of the furnace, then heated and reduced by circulating reduction gas, which enters in the middle of the furnace and exits at the top. This furnace is designed for uniform mass movement of the burden by gravity feed. The reduced iron is cooled in the lower part of the furnace by means of circulating cooling gas, which in turn prevents the re-oxidation of the final product. The reduced iron product is screened in order to reduce fines. These fines are briquetted to make them a usable product.

As an alternative, instead of cooling the DRI, it can made into hot briquetted iron (HBI).
The reducing gas, consisting basically of CO and H_2, is produced in a „reforming plant“, with reformer tubes filled with a catalyst. The catalyst is composed of high-porosity Al_2O coated with 5 - 10% Ni. 70% of the gas leaving the top of the oven is mixed with natural gas and heated with the remaining 30% of the top gas to produce rejuvenated reducing gas.

Advantages

- Shafts can be constructed in a range of sizes from 250,000 tpy to greater than 1.000.000 tpy.
- The technology has been world proven.
- Suitable as a mini-mill unit or as scrap replacement.
- Lower capital cost and environmental cost compared to the traditional blast furnace route.
- Replaces the coke oven and sinter plants and is therefore environmentally friendly.

Disadvantages

- Requires lump or agglomerated feed which means palletising fine ores.
- Iron charge must be of high quality with low decrepitation, as dust decreases performance of the shaft.
- Requires large amounts of natural gas.

Feed Requirements

- Feed material with a size of 5 - 50 mm required, with a high iron content (66%), low phosphorus and low gangue content. Gangue content of DRI is directly related to content of feed material, no control available in process.
- Fines in the shaft will lead to blocking and feed hang-up, (0.5mm material < 6%).
- Natural gas is the main fuel. Addition of natural gas to the reformed reduction gas allows control of the carbon content in the DRI.

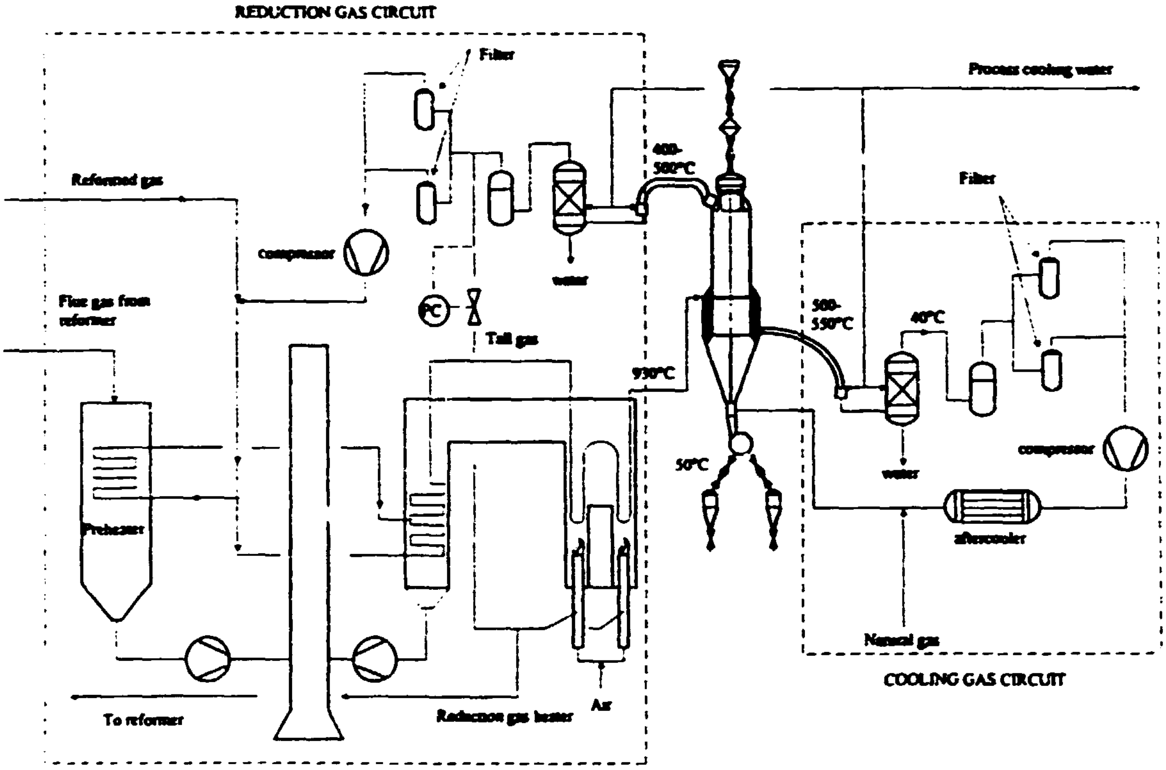
Plants and capacity

Customer	**Location**	**Capacity tpy**
QASCO	Umm Said,Qatar	400,000
ASCO	Ahwaz,Iran	1,200,00
Madeed I	Al-Jubail,Saudi Arabia	800,000
Madeed II	Al-Jubail,Saudi Arabia	650,000
ANSDIC	El Dikheila,Egypt	716,000
LISCO I	Misurata,Libya	1,100,000
NISCO	Mabarakesh,Iran	3,200,000
SGI	Labuan Island,Malaysia	650,000
Essar Steel I & II	Hazira	880,000
Essar Steel III	Hazira	440,000
NDIL	Roigod,India	1,000,000
SIDERCA	Campana,Argentina	330,000
SIDOR I	Matanzas,Venezuela	350,000
SIDOR II	Matanzas,Venezuela	1,275,000
Aandor	Villa Constitucian,Argentina	600,000
ISCOTT I & II (III)	Point Lisas,Trinidad & Tobago	840,000
MINORCA (OPCO)	Puerta Ordaz,Venezuela	830,000
VENPRECAR	Matanzas,Venezuela	600,000
Georgetown Steel	Georgetown,SC,USA	400,000
Sidbec-Dasco I	Contrecoeur,Que,Canada	400,000
Sidbec-Dasco II	Contrecoeur,Que,Canada	600,000
HSW	Hamburg,Germany	400,000
British Steel	Hunterston,Scotland	800,000
OEMK	Stary Oskal,Russia	1,667,000
Delta Steel	Aladja-Ovwain,Nigeria	1,020,000

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.5	tonnes
Natural gas	10.5	GJ
Electricity	125	kWh
Water	1.5	m^3
Labour	0.45	man hours

4.1.2 HYL (HYL S. A. Monterrey, Mexico)



Development of the HYL process began in the early 1950's with the HYL-I technology, which was a retort process working in batches. The first production facility with a capacity of 100,000 tpy of DRI was built in 1957 in Monterrey. Mexico. Further major retort-type plants were installed all over the globe in the 60's and 70's. The retort process was being replaced after 1980 by a continuous shaft-type furnace process, which has become known as HYL-III technology.

The HYL-III reactor is suitable for a wide range of pellets and pellet/lump ore mixtures. The main feature of the reactor is that it operates at a pressure of 5.5 bar. This therefore requires the use of a lock system for charging the Fe-carriers into the loading bin subjected to the reactor shaft pressure. Heated reducing gas enters the middle of the reactor and reduces the descending ore charge in counterflow into DRI. Having left the reduction zone, the DRI first enters the so-called isobaric zone which on the gas side separates the reduction zone from the cooling zone, while also ensuring the necessary uniform descent of the solid matter in the reduction zone. In the following conical section of the reactor, the sponge iron is cooled in counterflow by cooling gas injected from the bottom. The product is then continuously discharged at approx. 50°C through a rotary valve via either of two discharging lines, designed as lock systems similar to the loading facility. The top gas is first cooled and cleaned. Two thirds of this gas is recirculated, whilst the remaining third must be removed from the system as residual gas for removing from the process both the carbon dioxide and nitrogen. This residual gas is used for heating of gas heaters and reformers due to the significant H_2 and CO content. In the conical section of the reactor, the sponge iron is cooled and carburized by means of cooling gas flowing in the opposite direction. This gas after being de-dusted and enriched with natural gas, allows the control of the DRI carbon content. Alternatively, as with MIDREX, the reduced iron can be made into HBI.

The reduction gas is generated by steam reformers utilising a nickel catalyst and natural gas, whilst working at a pressure of 8 bar. Here, the hydrocarbons and steam are reacted at 800°C, to produce CO and H_2. The raw gas is cooled to 40°C to remove the steam content while also using the sensible heat -to generate saturated steam-, and is then admitted as fresh gas to the reducing gas circuit.

Advantages

- Shafts can be constructed in a range of sizes from 250,000 tpy to greater than 1,000,000 tpy.
- The technology has been world proven.
- Suitable as a mini-mill unit or as scrap replacement.
- Lower capital cost and environmental cost compared to the traditional blast furnace route.
- Replaces the coke oven and sinter plants and is therefore environmentally friendly.
- Removal of carbon dioxide increases reduction efficiency.

Disadvantages

- Requires lump or agglomerated feed which means pelletising fine ores.
- Iron charge must be of high quality with low decrepitation, as dust decreases performance of the shaft.
- Requires large amounts of natural gas.
- Requires more natural gas than MIDREX process.

Feed Requirements

- High grade feed material with low phosphorus and low gangue content. Gangue content of DRI is directly related to content of feed material, no control available in process.
- Fines in the shaft will lead to blocking and feed hang-up. (0.5mm material < 6%).
- Natural gas is the main fuel but other hydrocarbon feeds can be used.
- Sulphur content should be low to avoid catalyst poisoning in the reformer.

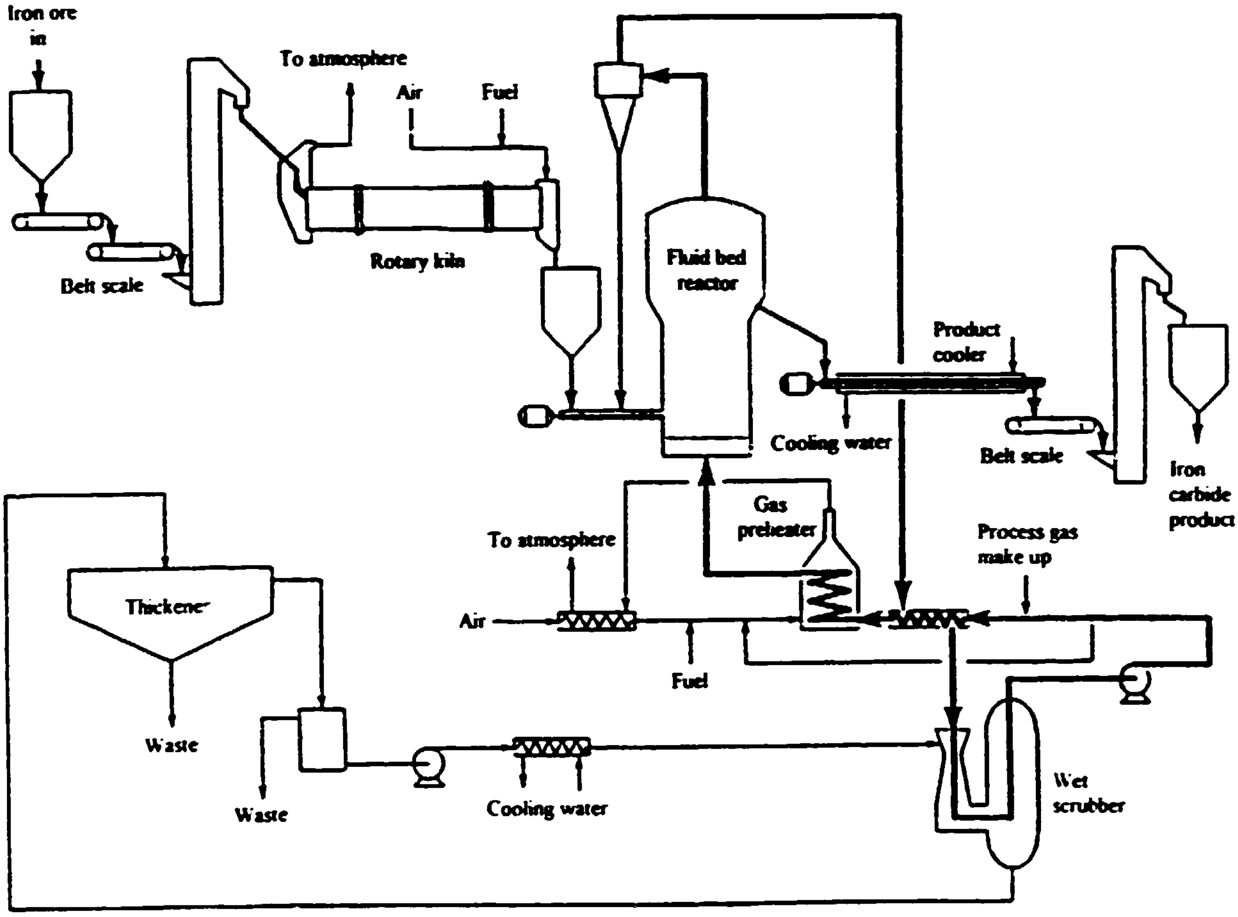
Plants and Capacity

Plant	Country	Capacity (tpy)
HYL-I (fixed bed)		
Hylsa 1M	Mexico	105000
Hylsa 2M	Mexico	630000
Tamsa	Mexico	280000
Usiba	Brazil	225000
Sidor 1	Venezuela	360000
Sidor 2	Venezuela	2110000
PTKS 1	Indonesia	560000
PTKS 2	Indonesia	560000
PTKS 3	Indonesia	560000
PTKS 4	Indonesia	560000
SEIS 1	Iraq	543000
SEIS 2	Iraq	925000
NISCO	Iran	1030000
HYL-III (moving bed)		
Hylsa 2M5	Mexico	250000
Hylsa 3M5	Mexico	500000
Sicartsa 1	Mexico	1000000
Sicartsa 2	Mexico	1000000
Grasim	India	750000
PTKS	Indonesia	1350000
PSSB 1	Malaysia	600000
PSSB 2	Malaysia	600000

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.5	tonnes
Natural gas	10.9	GJ
Electricity	110	kWh
Water	1.8	m^3
Labour	0.35	man hours

4.1.3 IRON CARBIDE



Iron carbide (Fe_3C) can be produced from iron ores and then used as a replacement for both hot metal and scrap in the EAF and BOF steelmaking routes. The process involves reacting fine iron ore with reducing gas (CO and H_2) at a temperature between 600 and 800°C in a fluidised bed reactor for 6 - 12 hours. From a chemical point of view, iron carbide can be considered to be DRI with 2 - 3% more carbon than that produced by the MIDREX process.

The fine iron ore is preheated and then enters the bottom of the fluidised bed reactor. A process gas comprising carbon monoxide, carbon dioxide, hydrogen, methane and water vapour enters the bottom of the reactor. The iron ore reacts with the hydrogen, combining with it's oxygen to form water (the only process by product). Carbon from the carbonaceous gases combines with the iron to form iron carbide - the end product. The iron carbide is then discharged and cooled. The top gas is dedusted in a cyclone, with the dust being recirculated to the process. The gas is washed in a scrubber, rejuvenated, preheated and recirculated to the reactor.

Advantages

- Fine ore process.
- Claimed non-pyrophoric product is safer to transport and store.
- Fine iron carbide is suitable for pneumatic transport.
- Higher carbon content increases fuel value of iron carbide.
- Suitable as virgin iron unit for mini-mills.
- Replaces scrap and some hot metal in conventional BOS, depending on temperature of injection and gangue content.

Disadvantages

- Gangue content makes iron carbide difficult to use in large quantities in steelmaking.
- May be difficult to handle using conventional equipment in integrated and mini-mills due to powdered form.
- Unproven technology to date.
- Commercial plant still in start-up phase.

Feed requirements

- Very low gangue or easily benificiated ores will be preferred, especially with respect to Al_2O_3 and SiO_2.
- Natural gas is the preferred reductant for the process, however, coal could also be used after gasification.

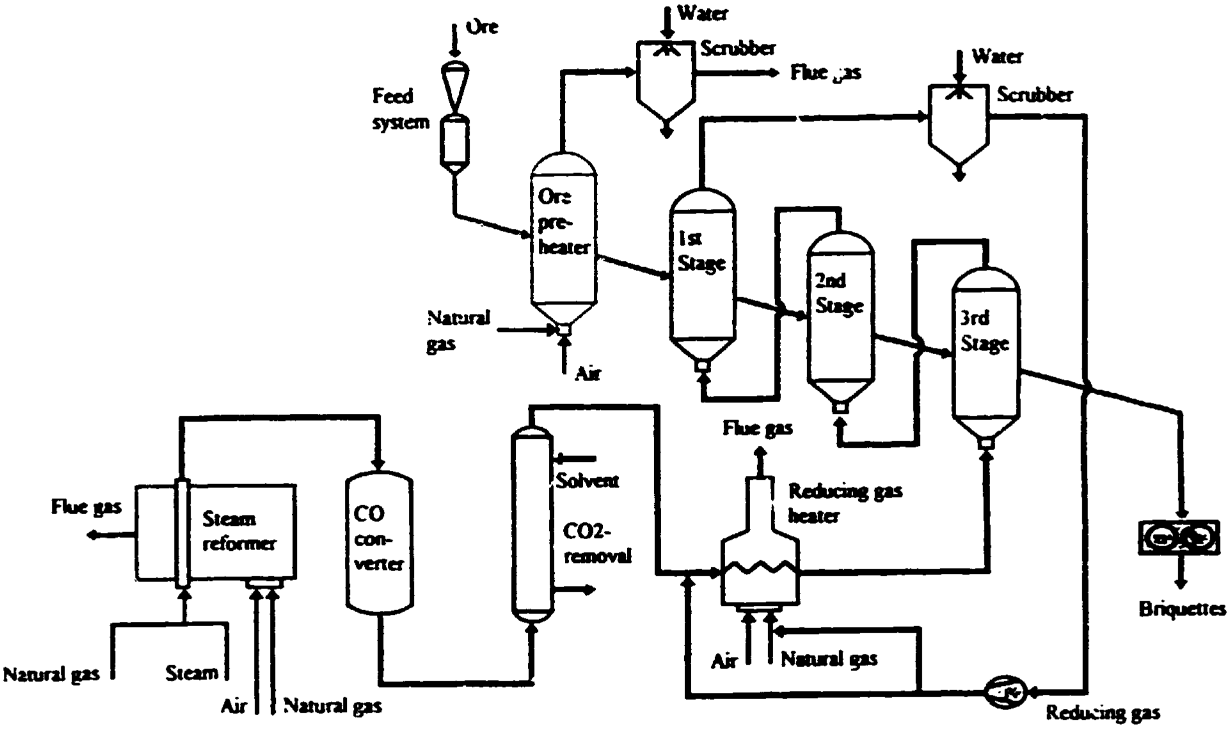
Plants and capacity

NUCOR	Trinidad-Tobago	320,000 tpy	(not yet in production)

Raw Material Consumption per tonne Iron Carbide

Iron ore (lump)	1.35-1.4	tonnes
Natural gas	14.1	GJ
Electricity	70	kWh
Water	1.5	m^3
Labour	0.45	man hours

4.1.4 FIOR (Fine Iron Ore Reduction)



The iron ore is preheated in a fluidised bed reactor, followed by consequent reduction in three further reactors under a pressure of 10 bar and about 880°C. The final reduced iron product is briquetted, cooled and air passivated.

Natural gas is transformed in a steam reformer, into the reduction gas. The reduction gas enters the last reactor and flows in a countercurrent direction from the top of the last reactor, to the bottom of the previous reactor. Upon exiting the first of the reduction reactors, the gas is scrubbed and rejuvenated, heated and recirculated.

Advantages

- Fine ore process.
- A variety of fuels can be used for the reductant.
- Process can be scaled from 400,000 tpy to 1.5 Mtpy.
- Suitable as virgin units for mini-mills and partial scrap substitution in conventional steelmaking.

Disadvantages

- Gangue content makes DRI difficult to use in large quantities in conventional BOS.
- Process unproven on large scale.
- Requires source of low cost natural gas for optimum economic production.

Feed Requirements

- Feed ores required are low gangue, sized between 5.0mm and 50 μm.
- Minus 50μm material maximum 20%.
- Ores should have low decrepitation and moisture content, coupled with high reducibility.
- Wide variety of feedstocks can be used but low cost natural gas is preferred.
- Used gases are scrubbed of water and CO_2 and recycled with additional make up gas.

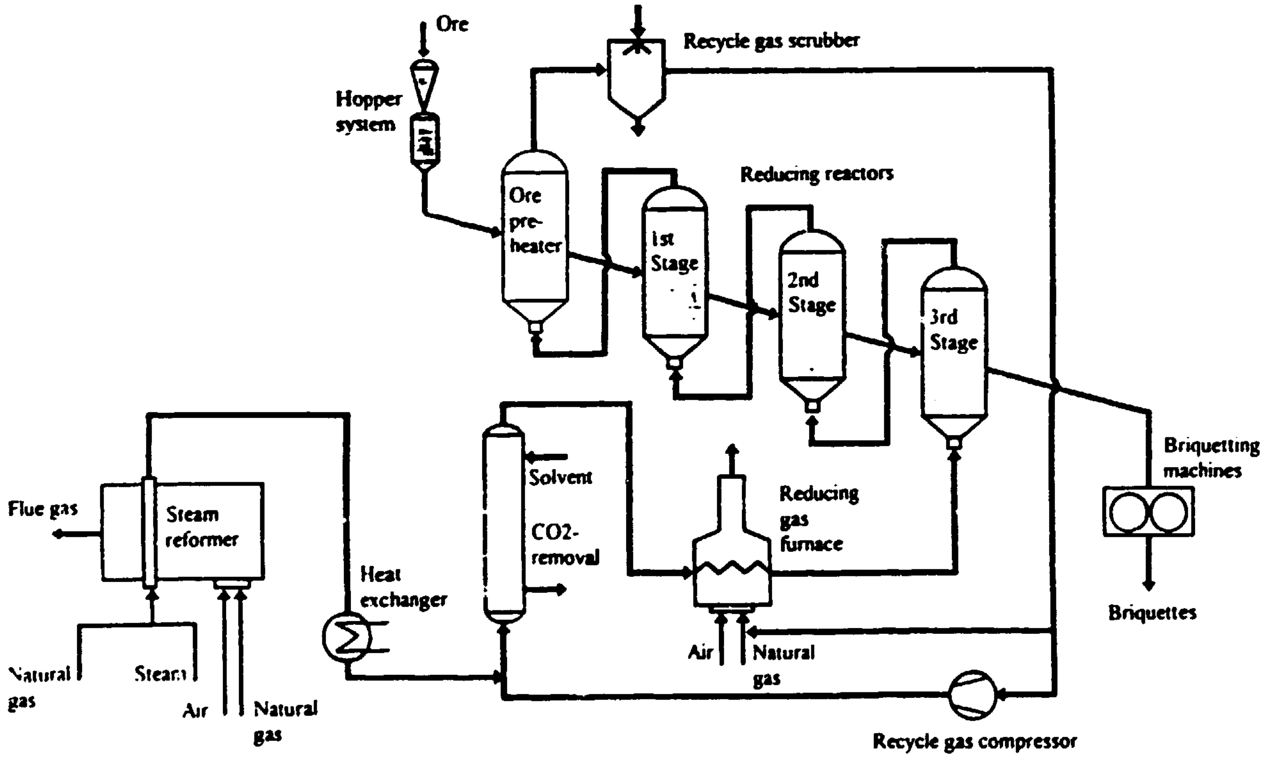
Plants and capacity

Puerto Ordaz	Venezuela	400,000 tpy

Raw Material Consumption per tonne DRI

Iron ore (fine)	1.5	tonnes
Natural gas	16.2	GJ
Electricity	195	kWh
Water	5.5	m^3
Labour	0.6	man hours

4.1.5 FINMET



The Finmet process is a further development of the FIOR process. The difference is that the reducing gas leaves the first reduction reactor and enters the bottom of the preheating reactor. From there, the gas is scrubbed. CO_2 is removed and the gas is rejuvenated and recirculated. Also absent in this process is the CO converter.

Raw Material Consumption per tonne DRI

Iron ore (fine)	1.5	tonnes
Natural gas	12.0	GJ
Electricity	145	kWh
Water	2.5	m^3
Labour	0.4	man hours

4.2 Techno-economical aspects

Comparison of DRI Processes - For a country utilising <u>**low cost natural gas**</u>

Gas Based | MIDREX
Plant size (Mt/a): 0.4

	Unit Cost	*Units*	*Cnsmptn /t DRI*	*Total $*
Iron ore superlump	42.5	tonnes	1.5	63.0
Natural gas	2.00	GJ	10.5	22.6
Electricity	0.08	kWh	125	10.0
Water	0.44	m3	1.5	0.7
Labour	41	man hours	0.45	18.5
R & M				5.6
				120.4

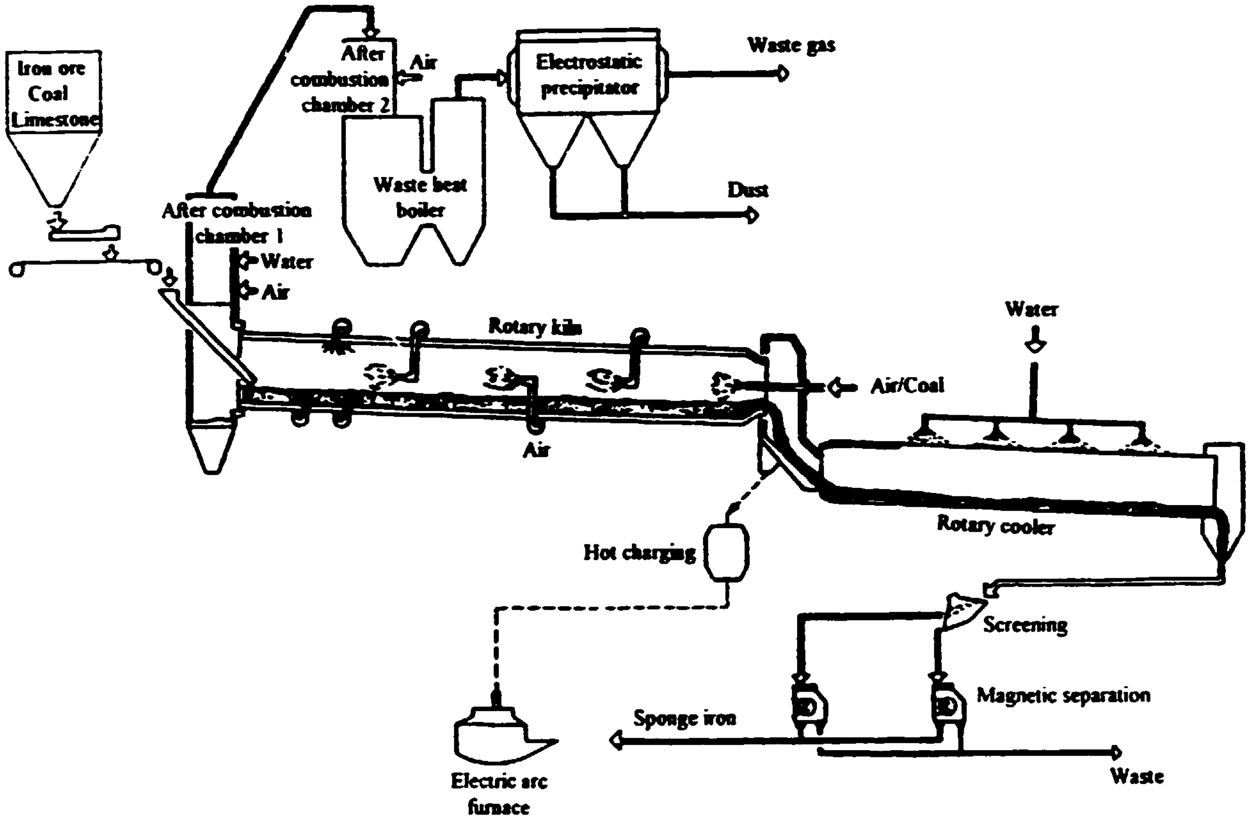
Coal Based | SL/RN
Plant size (Mt/a): 0.7

	Unit Cost	*Units*	*Cnsmptn /t DRI*	*Total $*
Crushing/grinding	2			-
Iron ore superlump	42.5	tonnes	1.5	63.0
Coal inc. transportn	62	tonnes	0.7	43.4
Fluxes & Binders	25	tonnes	0.05	1.3
Electricty	0.045	kWh	70	3.1
Water	0.65	m3	2.5	1.6
Labour	24	man hours	0.5	12.0
R & M				9.7
				149.9

5. Coal based Processes

5.1 Process alternatives

5.1.1 SL/RN



The raw materials ore and coal, are proportioned in predetermined ratios and charged to the reduction kiln. After drying and preheating of the charge to the reduction temperature, the iron oxides of the ore are reduced by means of CO, an uninterrupted supply of which is ensured by the conversion in the kiln of the coal used. The temperatures required by the process are provided and controlled by predetermined rates of combustion air injected through shell blowers arranged along the kiln length.

At temperatures between 1000 and 1100°C, the ore is reduced in the solid state to form DRI. After being discharged from the rotary kiln, the DRI is cooled to ambient temperature together with the remaining char in a cooler arranged downstream, for the purposes of avoiding reoxidation and conditioning the materials for subsequent handling.

Separation of the DRI from the non-magnetic kiln discharge material is effected by screening. Smaller fractions are removed in a magnetic separation system. In specific cases, direct charging of the hot rotary kiln product (DRI plus residual carbon) to the melting unit is possible. Normally, the rotary kiln off-gases are led countercurrent with the material charge, leaving the kiln at the feed end. After passing through a dust chamber, they are burnt and then cleaned.

Advantages

- Process can utilise a wide range of fuels, including low rank coals, fuel oils, natural gas etc., ferrous feeds, pellets, lump ores and even ironsands.
- Product suitable as virgin iron units for EAF.
- Unburnt char can be recycled to reduce energy consumption.

Disadvantages

- High quality DRI product requires high grade ferrous feed and low ash fuel limiting raw material sourcing.
- High reactivity chars/fuels required for high productivity, with high ash melting points.
- Efficient dust collection necessary as particular raw material combinations can generate substantial amounts of dust.
- Kilns are on a small scale, requiring multiple units for large scale production.

Feed requirements

- Process has been run on a wide range of pellets, lump ores and with modifications, ironsands.
- Ferrous material should have high reducibility with low degradation properties during rapid heating.
- Low gangue materials preferred.
- Wide range of fuels can be used, but generally low ash (<15%), high volatile, highly reactive, low sulphur and low decrepitation coals preferred; low reactivity fuels e.g. anthracite, require supplementary fuel fed through burner or air ports. Non fluidising coals must be used to reduce carbon losses as dust
- Larger coals (typically 15mm) are added with the ferrous feed and flux (60%), finer coals(5-15mm) are added through the kiln exit port (40%). Fuel rate around 800 kg/t DRI for 30% vol. sub-bituminous coal.
- Flux added to prohibit coal ash from joining DRI. Sized generally to 3mm, mainly added with ferrous feed.

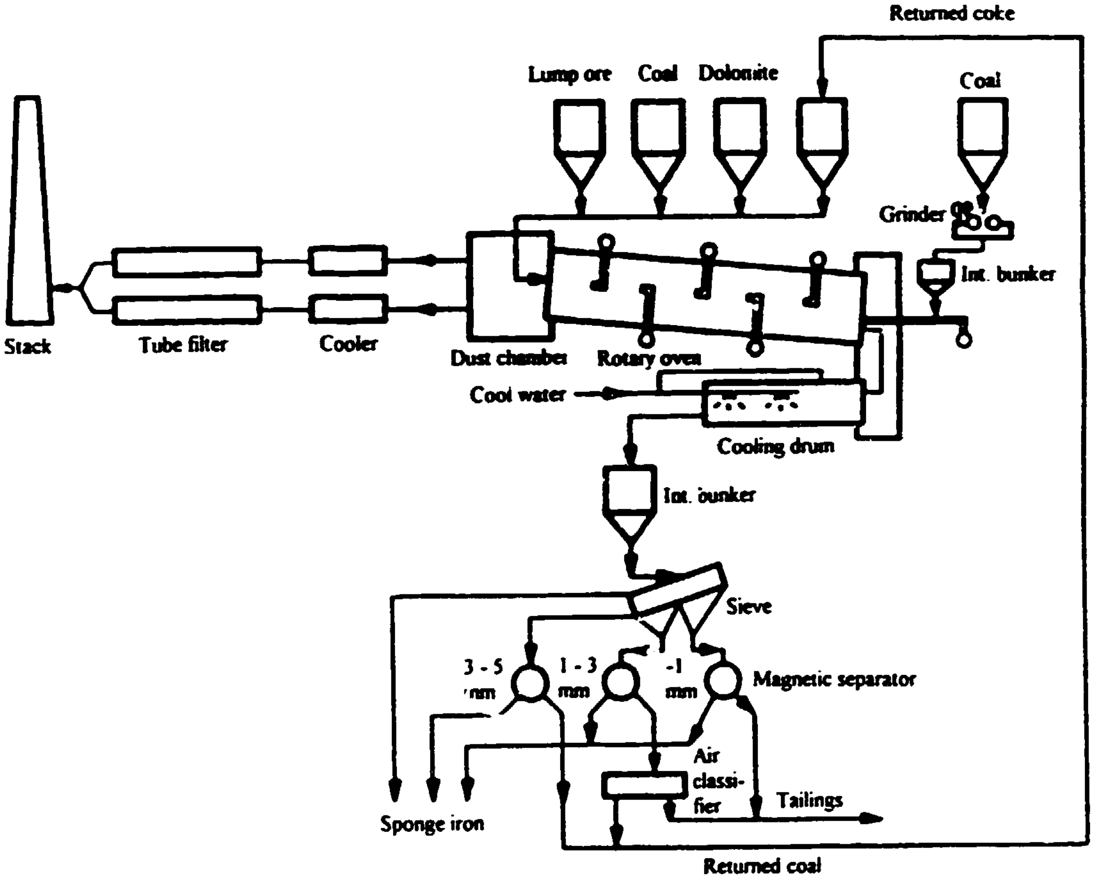
Plants and capacity

Plant	*Capacity (tpy)*	*Kiln size (m)*
Western Titanium	15,000	2.4 x 30
Highveld I	2,000,000	4.0 x 60
New Zealand Steel I	175,000	4.0 x 75
Acos Finos Piratini	60,000	3.6 x 50
Stelco	360,000	6.0 x 125
Nippon Kokan	400,000	6.0 x 70
Siderperu	120,000	2.9 x 62
Unido/SIIL	35,000	3.0 x 40
Highveld II	600,000	4.0 x 60
ISCOR/ Vanderbijlpark	720,000	4.8 x 80
New Zealand Steel II	900,000	4.6 x 65

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.43	tonnes
Coal	0.75	tonnes
Electricity	60-80	kWh
Water	2-3	m^3
Labour	0.4-0.6	man hours

5.1.2 KRUPP-CODIR



Lump ore or pellets are charged together with reduction coal, return char and raw dolomite or limestone as desulphurizing agent into an inclined rotary kiln. The charge runs countercurrent to the hot gases through the kiln and is heated to a temperature which causes the reaction between the coal and the oxygen contained in the ore.

From the discharge end of the kiln, fresh coal is injected countercurrently to the charge in the direction of the kiln axis. This coal, which should have a high volatile hydrocarbon content, is injected by compressed air in such a fashion to ensure a widespread distribution in the high-temperature zone, thus guaranteeing that it is well mixed with the charge due to the rotary movement of the kiln. The volatile hydrocarbons in the coal are released and cracked and act as additional and very effective reducing agents due to the hydrogen content. Depending on the reactivity of the charge coal, temperatures in the range 950 to 1150°C are measured in the burden. After the charge has stayed in the kiln for approx. 8 to 10 hours it is discharged via a chute to a cooling drum and indirect spray-water-cooling. By way of screening and magnetic separation, the sponge iron is separated from the non-magnetic particles. In an air jigging machine, surplus char is separated from ash and the desulphurizing agent. In order to cut back the consumption of fresh coal, the char is recycled in the process.

Plants and capacity

Plant	*Capacity (tpy)*	*Kiln size (m)*
Dunswart Steel (R.S.A)	150,000	4.6 x 73.5
Borbeck (Germany)	200,000?	3.6 x 110

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.4.	tonnes
Fluxes & Binders	0.05	tonnes
Coal	0.6	tonnes
Electricity	70*	kWh
Water	2.5*	m^3
Labour	0.5*	man hours

* estimate

Iron ores and pellets used in industrial CODIR kilns

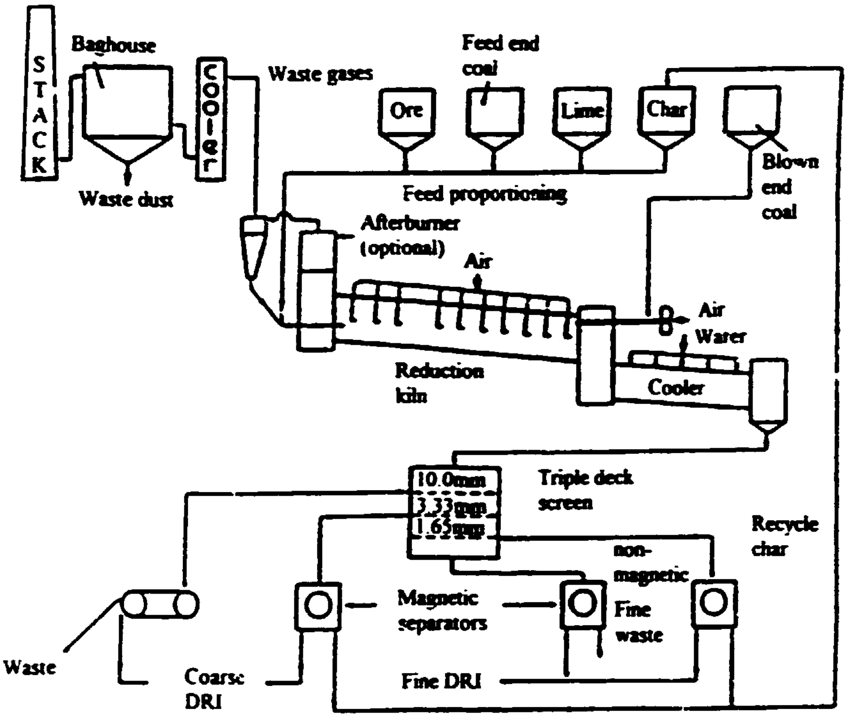
	Origin	Fe_{tot} %	SiO_2 %	*S* %	*other* %
Sishen[1] lump ore	S.Africa	66.8	3.0	0.03	-
Postmaasburg[1] lump ore	S.Africa	66.9	2.5	0.02	-
Itabira[2] lump ore	Brazil	67.8	0.8	0.01	-
Solmine[1] lump ore	Italy	65.6	2.72	0.01	0.28 (Pb + Zn)
Kromdrai[1] lump ore	S.Africa	67.1	1.20	-	0.10 Sn

1)Processed in Dunswart Steel, South Africa
2)Borbeck, Germany

Reducing coals used in industrial CODIR kilns

Coal type	C_{fix} %	*Volatile* %	*S* %	*Ash* %	*Cv* MJ/kg
Bituminous Coal	58	28	1.0	13	28.8
Semi-anthracite	68	13	1.3	17.7	27.7
Anthracite	78	11	0.8	10.2	30.6
Coke breeze	84.5	4	0.5	11.0	29.5

5.1.3 Other rotary kiln processes (ACCAR, DRC, TDR)



DRC Process

These processes are similar to SL/RN and KRUPP in that the reduction takes place in a rotary kiln. The ACCAR has the ability to utilise liquid, gas or solid fuels or in fact a combination. The DRC and TDR use only coal for reduction. In the TDR process, the coal may be first dried using a drum oven before the main oven.

Plants and capacity

ACCAR:	Niagara Metals, Canada	30,000 tpy
	Orissa Sponge Iron, India	150,000 tpy
DRC:	Rockwood, USA	60,000 tpy
	Scaw Metals, Germiston (SA)	75,000 tpy
TDR:	The Tata Iron & Steel Co. Ltd. Jamshedpur, India	90,000 tpy

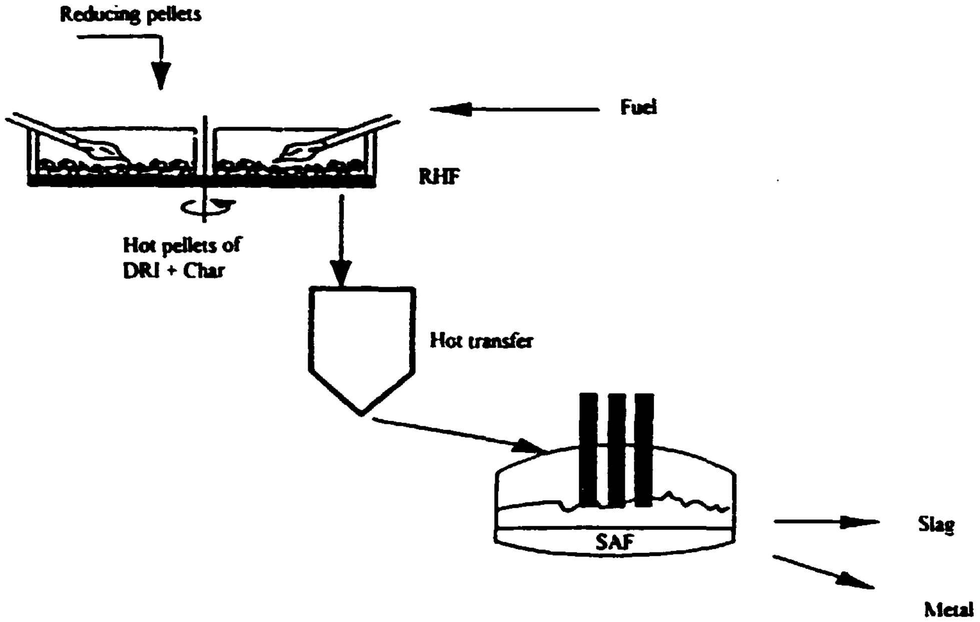
Raw Material Consumption per tonne DRI

ACCAR

Iron ore (lump)	1.5	tonnes
Energy - coal	12.6	GJ
Energy - oil	13.6	GJ
Energy - Natural gas	14.7-15.5	GJ
Fluxes & Binders	unknown	tonnes
Electricity	50-60	kWh
Water	1.0	m^3
Labour*	0.5	man hours

* estimate

5.1.4 FASTMET



Fine iron oxides and coal dust are mixed and pelletised and charged into the hot rotary hearth in two or three layers. The hearth is heated in counterflow by means of gas and/or coal burners. The „green" pellets are heated in the first third of the hearth by gas and wall radiation to the reduction temperature. The main energy source used in this zone is the carbon monoxide obtained from the reduction zone. Reaction between the carbon present in the pellets and the iron oxide begins when the reduction temperature is reached. The burners in the remaining two thirds of the hearth are operated substoichiometrically in graduated groups with a major portion of the energy coming from partial combustion of the produced carbon monoxide. Only a balancing portion of energy is therefore required to meet requirements.

Due to the high temperature of 1100 to 1350°C, the pellets are nearly completely metallised during one revolution of the hearth, less than 15 minutes. Excess carbon not consumed in the reduction, remains in the sponge iron. Therefore, the carbon content of the final product can be controlled by the initial carbon content within the range 1.5 to 10%. This is a primary feature of this process.

Advantages

- Fine ore process
- Claimed low capital and operating costs
- A variety of fuels can be used.
- Suitable as virgin iron units for min-mills
- Process can accept steel plant waste.
- Replaces scrap and some hot metal in conventional BOS, depending on temperature of addition and gangue content.

Disadvantages

- Gangue content makes DRI difficult to use in large quantities in steelmaking, especially when combined with the reductant coal ash.
- Small capacity.
- Process unproven commercially.

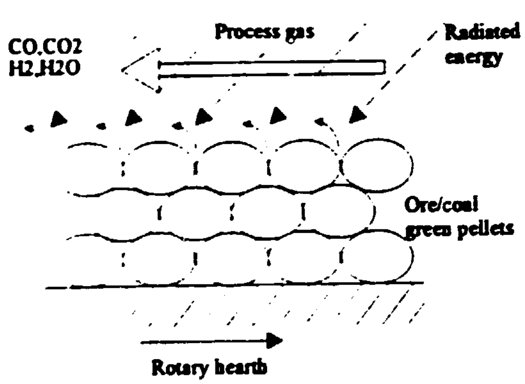
Feed requirements

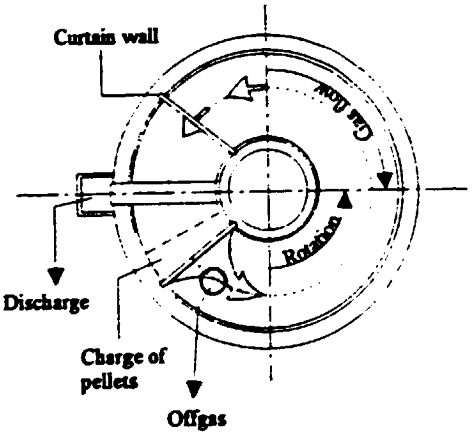
- Process has been tested for a wide range of ores, including steel plant dusts.
- Process prefers fine, low gangue material. Lump ores will require milling to give >80% at -45μm. Moisture must also be low.
- However, highly reactive and strong ores are likely to be beneficial.
- Process specifies fuel: <20%ash, >59% FC, 70-80% -75μm.
- Overall, low ash, low VM, low S coals are preferred.

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.5	tonnes
Coal	0.41	tonnes
Fluxes & Binders	0.02	tonnes
Electricity	60	kWh
Water	1.1	m^3
Labour	0.3	man hours

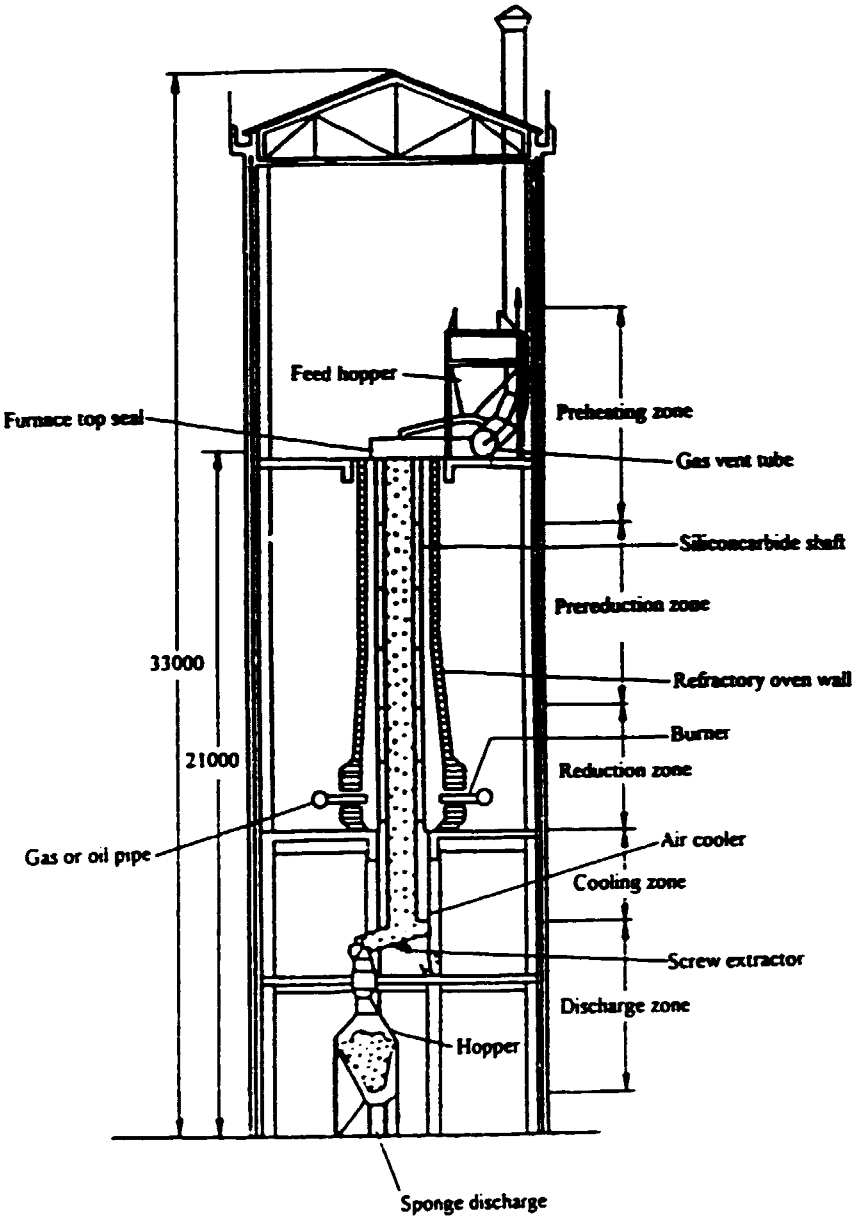
INMETCO





The Inmetco process is basically a derivative of the FASTMET process. Comprehensive tests have been conducted using steel plant wastes as the feed material. The ability to volatise the heavy metals, such as Zinc and Tin and condense them as a secondary dust, means this process is beneficial for recycling. There is to date however, only a pilot plant built, in Ellwood City, USA with a capacity of 150,000 tpy.

5.1.5 KINGLOR-METOR



The main feature of this process is the reduction is carried out using radiated heat through a silicon carbide shaft, at a temperature of 1050°C. The charge of ore and coal enters the top through a charging system and descends through the reduction zone and then a cooling zone by the action of gravity. The disadvantage is the plant can only be used for small scale operations due to the loss of heat conductivity with increasing wall thickness.

Remark: The COREX-Process, a coal-based reduction process has become more and more important for iron and steel production in the last years - especially in regions where neither coking coal nor natural gas is available.

The basic COREX process is a smelting reduction process with a liquid final product (hot metal) and not a direct reduction process. Therefore the process is not treated in this paper. The combination of the COREX-process with a Direct Reduction Process using the top gas of the COREX process is an interesting alternative to the classical Direct Reduction Process (see 6.2 and 7)

5.2 Techno-economical aspects

Comparison of DRI Processes - For a country utilising **low cost coal**

Gas Based MIDREX
Plant size (Mt/a): 0.4

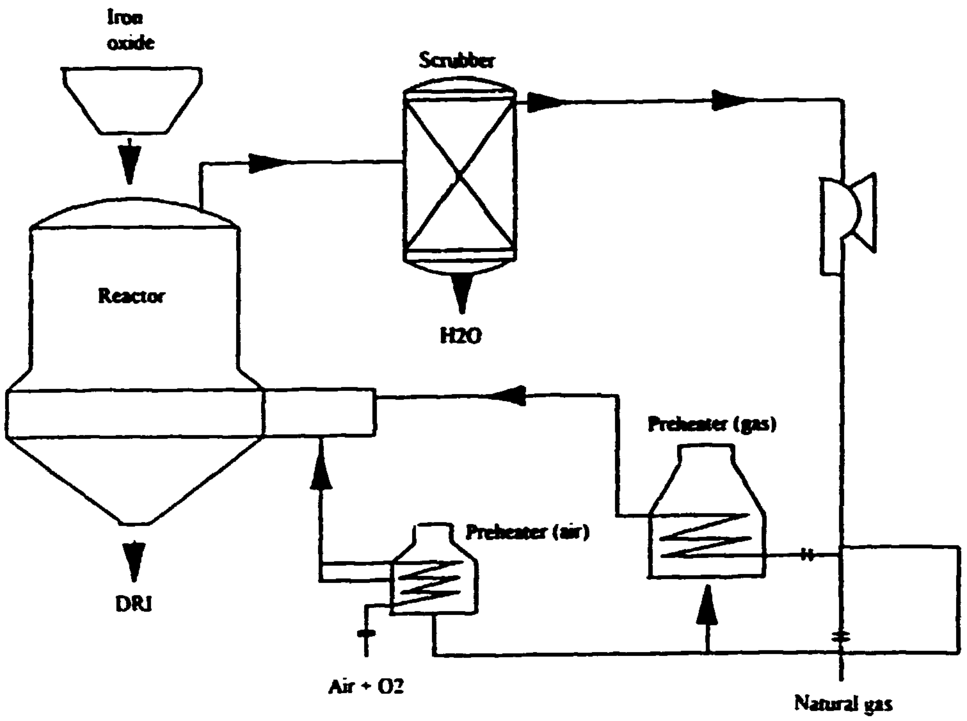
	Unit Cost	*Units*	*Cnsmptn /t DRI*	*Total $*
Iron ore superlump	42.5	tonnes	1.5	63.0
Natural gas	5.00	GJ	10.5	52.5
Electricity	0.08	kWh	125	10.0
Water	0.44	m3	1.5	0.7
Labour	41	man hours	0.45	18.5
R & M				5.6
				150.3

Coal Based SL/RN
Plant size (Mt/a): 0.7

	Unit Cost	*Units*	*Cnsmptn /t DRI*	*Total $*
Crushing/grinding	2			-
Iron ore superlump	42.5	tonnes	1.5	63.0
Coal inc. transportn	35	tonnes	0.7	24.5
Fluxes & Binders	25	tonnes	0.05	1.3
Electricty	0.045	kWh	70	3.1
Water	0.65	m3	2.5	1.6
Labour	24	man hours	0.5	12.0
R & M				9.7
				131.0

6.0 Future developments

6.1 AREX-MIDREX



A further modification of the MIDREX process is the AREX-MIDREX process. In this process, the hot DRI provides the mechanism for generating the reduction gas from partially oxidised natural gas. This gas rises to the top of the reactor to reduce a descending charge. This effectively combines the furnace and reformer from the original Midrex process into a single shaft furnace. To date, this is only an experimental process and has yet to be proven commercially.

Advantages

- Small production units are feasible, with flexible options for processing DRI.
- Low energy consumption compared to existing DR processes such as Hyl and Midrex.
- Wide range of fuels can be used as sulphur levels are of lesser importance as DRI auto reforms input gas.
- Negates the need for coke ovens, sinter plant and blast furnace ironmaking.
- No internal moving parts reducing wear and maintenance problems.
- Lower capital and environmental costs compared to CO/BP/BOF

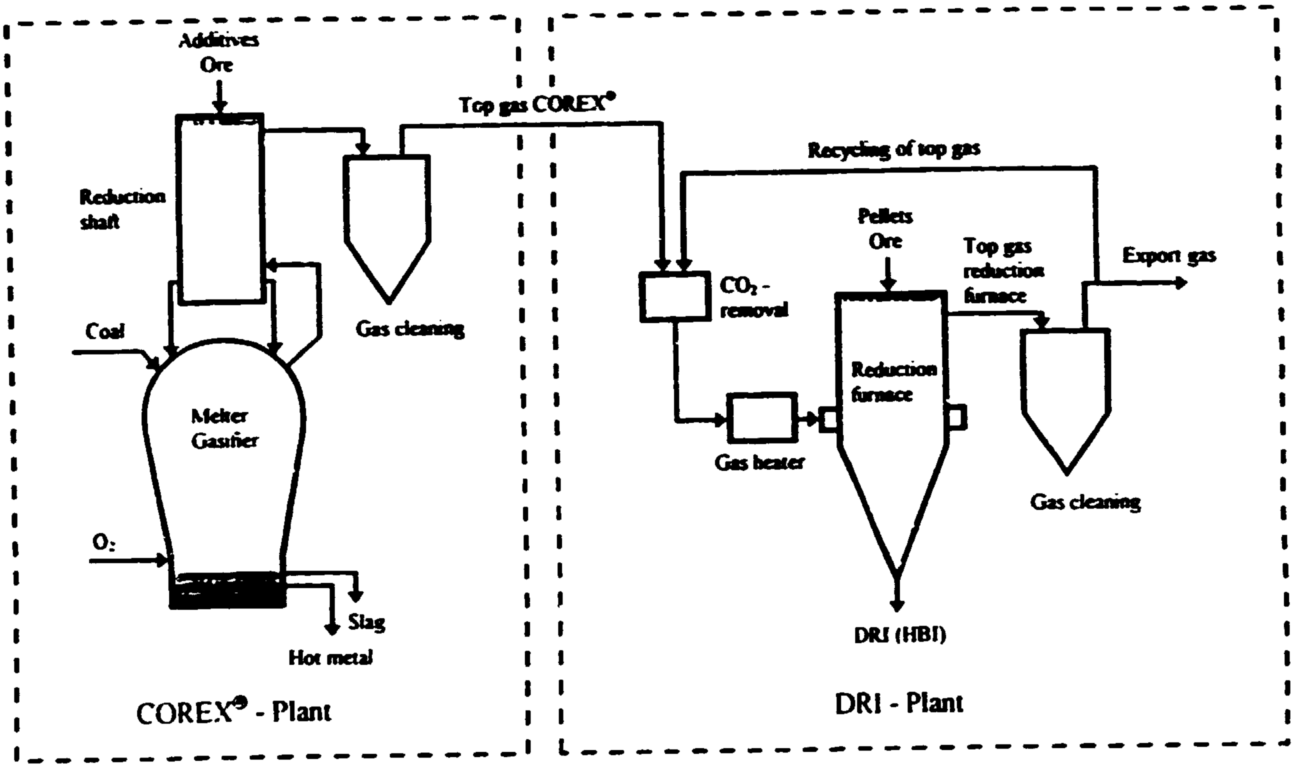
Disadvantages

- Unproven technology on a large commercial scale
- Ferrous burden must be high grade with low decripitation as dust is very deleterious to shaft performance.
- Requires lump ore or agglomerated feed, which means pelletising of fine ores.

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.5	tonnes
Natural gas	9.7	GJ
Electricity	115	kWh
Water	1.5	m^3
Labour	0.45	man hours

6.2 COREX-DRI



The top gas from a COREX plant could be utilised and provide the reduction gas for a secondary furnace. The CO_2 is first removed and the gas is heated. The gas enters the bottom of the oven and passes out from the top, is cleaned in a srubber and a portion therof is recycled back to the process. The remainder is used as export gas for power generation.

Advantages

- Top gas can be used for DRI production.
- Small production units are feasible, with flexible options for processing DRI.
- Low energy consumption compared to existing DR processes such as Hyl and Midrex.
- Negates the need for coke ovens, sinter plant and blast furnace ironmaking.
- No internal moving parts reducing wear and maintenance problems.
- Lower capital and environmental costs.

Disadvantages

- Ferrous burden must be high grade with low decripitation as dust is very deleterious to shaft performance.
- Requires lump ore or agglomerated feed, which means pelletising of fine ores.

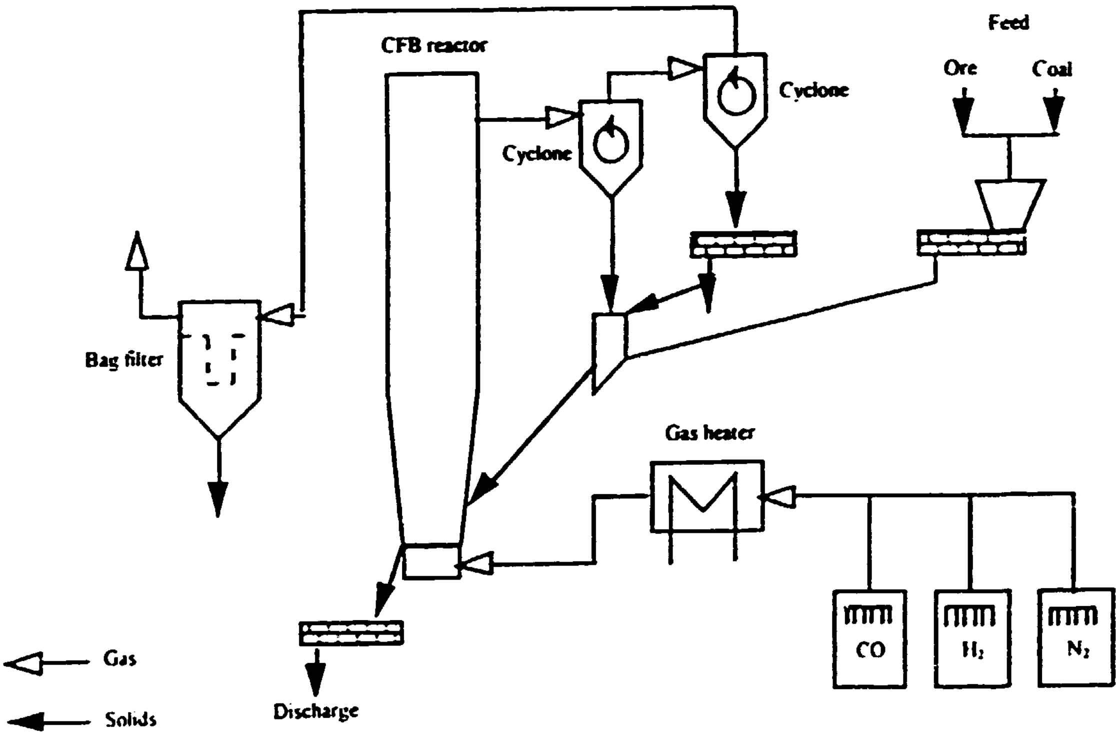
Plants and capacity

South Korea	750.000 tpy	(ordered 1994)

Raw Material Consumption per tonne DRI

Iron ore (lump)	1.45	tonnes
Energy	10.5	GJ
Electricity	100	kWh
Water	1.5	m^3
Labour	0.35	man hours

6.3 Circulating Fluid Bed (CFB)



Fine ores and coals are reduced in a fluidised bed reactor at temperatures between 850 and 1150°C. The reduction and fluidising gases comprising CO, H2 and N2 are added at the bottom of the reactor, with the feed material entering via a gas tight sluice. The temperature is maintained by additional heaters, whilst the DRI product is discharged and processed e.g. briquetted or added directly to a smelter, through the bottom of the reactor. Waste gases are scrubbed and the dust recycled back to the process.

Advantages

- Process can utilise a wide range of coals
- Basic process commercially proven
- Closed and efficient energy system.
- Environmentally friendly, i.e. very low generation of wastes.
- Can eliminate coke ovens, sinter plant and blast furnace.
- Appears suitable for ironsands.
- Highly flexible technology, can produce wide range of metallisation.

Disadvantages

- Not commercially proven for the production of highly metallised DRI.
- All materials must be dried and of low gangue content.
- Small scale process in the order of 100,000 tpy. DRI.
- Raw materials handling problems due to fine particle processing.

7.0 Capacity limitations

The dimensions of the modern mini-mills are in the range 700,000 to 1.5 million tonnes of steel per year. To be able to produce also high quality steel for use in making flat products, a high quality feed material is necessary. This feed material is produced by *Direct Reduction Plants*.

Gas based DRI plants are built up to a capacity of 1.0 million tonnes per unit nowadays. Direct reduction plants using a rotary kiln working on a coal basis, have a maximum unit capacity between 200,000 and 300,000 tonnes per year. To meet the capacity requirements of mini-mills more units must be installed.

Due to the new development of EAF's, with the possibility of a higher feed of pig iron up to 50% of the total charge, a further alternative based on coal is possible. Particularly the combination of COREX and DRI. Using this combined unit for production of hot metal and sponge iron, up to 1.5 million tonnes can be produced in one line. The addition of obsolete scrap allows an adaptation of capacities.

In each case, the produced quantity of steel remains on a very high level and therefore meets similar requirements of quality, which is usual for integrated steelworks. More than that, also a high flexibility according to the produced capacity and quality is achieved. By combining DRI production and eventually a slight addition of obsolete scrap, a very wide range of steels can be produced. In this case the advantage of mini-mills with low investment costs will come to fruition. Further more, those mini-mills are much more flexible with requirements of the customers and deliveries „just in time".

To summarize:

In countries with economic coal prices, the production of sponge iron with rotary kilns or the combined production of hot metal and sponge iron according to the COREX-DRI combination, is a favourable alternative to produce high quality steel, without being dependent on large scrap quantities and on the fluctuations in scrap market prices.

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